Modeling Bacterial Transport and Fate at Southport Beach, Connecticut

ABSTRACT

The water quality at beaches is critical for the health and safety of users and thus important for state agencies managing these resources. The need for a predictive capability to predetermine beach closures is often based on statistical approaches built from empirical regressions relating rainfall, temperature, salinity and other environmental parameters to elevated pathogen levels. Although statistical models can suffice for many situations a combined approach that incorporates deterministic (processed-based) models can offer more detailed information on closure duration and extent and is potentially more accurate. The purpose of the example presented here is to demonstrate how an integrated hydrodynamic and pollutant transport modeling framework can be used to determine both the location and relative contribution of bacteria sources responsible for closure of shellfish beds at Southport Beach in Connecticut as well as to predict future bacteria levels. To support the model system's data needs, a field program was performed that included physical, chemical and bacterial measurements. The hydrodynamic model was calibrated to field data, and provided currents over time and space for use in the subsequent pollutant transport calculations. Two different pollutant transport modeling approaches were used: a concentration-based calculation and a particle-based calculation. The particle-based model can be run both forward and backward in time. In the forward mode the model forecasts the evolution of pollutant plumes from specified source locations to provide predictive capability. In the backward mode the model hindcasts the likely source locations that would affect a specified resource area, essentially numerically tracking sources.

INTRODUCTION

The Problem

- Beaches and shellfish beds often closed due to exceedances of pathogen water quality criteria
- Elevated fecal coliform (FC) bacteria contamination (greater than 14 col/100 mL) cause closure of recreational shellfish beds in the Southport Beach area of Southport Harbor on Long Island Sound
- Location and relative contribution of bacterial sources unknown

Project Objectives

- Determine the location of bacteria sources responsible for shellfish beds closure in Southport Harbor
- Determine the relative contribution of each source to focus Best Management Practices (BMPs) on source reduction for greatest benefits
- Develop a model application that can be utilized for similar problems in other areas

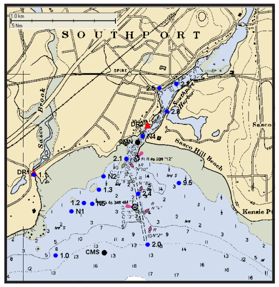
The Solution

- Execute a combined field program and modeling study

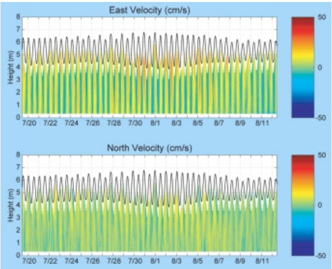
FIELD PROGRAM

ASA designed a field program to collect the data necessary to calibrate and run the models for the summer of 2004. The field program was organized into three components: physical and chemical measurements, bacterial measurements, and a dye study.

Physical and chemical data were collected continuously from 19 July to 12 August 2004 in Southport Harbor. An acoustic Doppler current profiler (ADCP) was deployed on the bottom to measure the vertical structure of horizontal currents and tide height. Water column profiles of conductivity, temperature and depth were also measured at eleven locations in Southport Harbor during deployment and retrieval of the ADCP. In addition, meteorological data was acquired from NOAA's National Climate Data Center and stream flow data was acquired from the Sasco Brook gauge maintained by the U.S. Geological Survey.



Location of sampling stations: current meter stations (black circles), hydrographic profile stations (blue circles) and dye release sites (red triangles).



Speed contours as a function of depth and time from the ACDP deployment, revealing that the primary flow is tidally driven in a generally east-west direction with little structure in the vertical. Water depth recorded by the ADCP is shown by the solid black line. A strong semi-diurnal (12.42 hr) signal is evident, as well as the spring-neap cycle.

Three intensive one-day bacterial surveys (20 July, 27 July and 10 August 2004) were conducted simultaneously with the deployment of moored instruments and dye studies. In each intensive survey, water samples were collected six times over the tidal cycle at fourteen locations and analyzed for FC concentrations.

Dye studies were conducted on 20 July and 27 July at different dye release sites. Plume tracking in the harbor was performed by boat with an integrated fluorometer and DGPS system.

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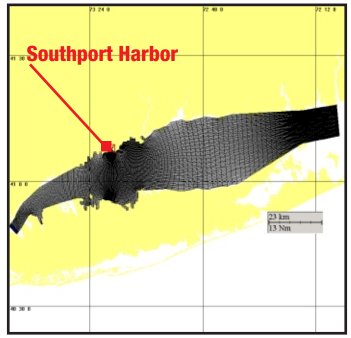
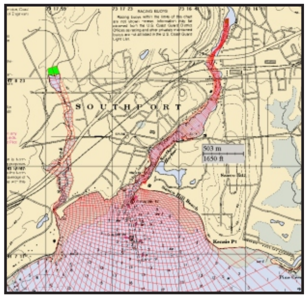
MODELING

A modeling system that predicts the circulation and pollutant transport was needed. -A unique requirement of the model system was the ability to estimate source locations and strengths as well as the more typical pollutant distributions from those sources. Toward this end ASA's WQMAP hydrodynamic and pollutant modeling system was used with components from ASA's OILMAP modeling system.

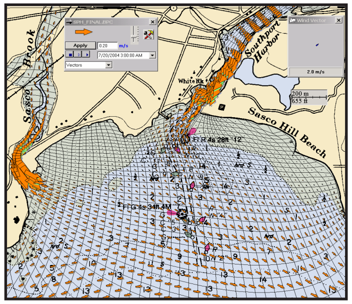
WQMAP includes a boundary-fitted, two-dimensional hydrodynamic model that generates water elevation and velocity and a pollutant transport model that determines concentrations resulting from known sources.



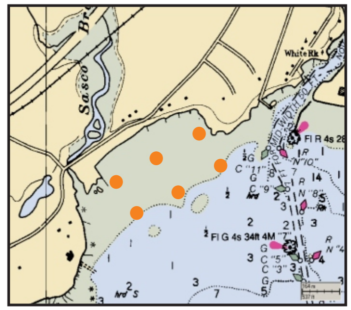
Map showing model grid, covering Long Island Sound. Southport Harbor is enclosed by a red box.



Details of the model grid within Southport Harbor.

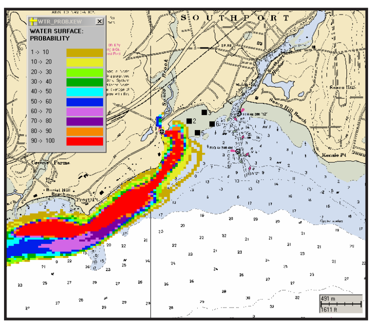


Model-predicted depth averaged currents at maximum ebb in Mill River.

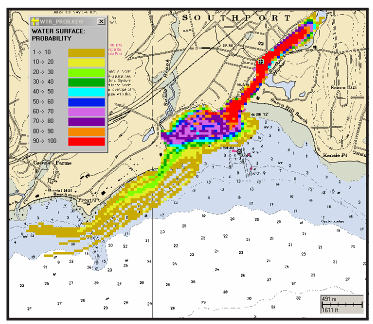


Location of six receptors used in the backward mode model runs.

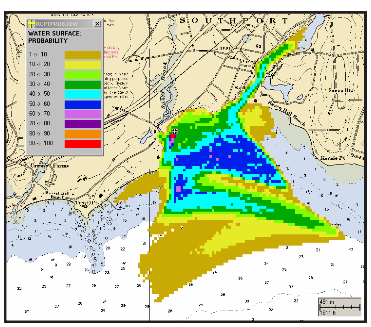
OILMAP is a particle-based model system that uses the WQMAP hydrodynamic model output to estimate either resulting concentrations from known sources (forward tracking) or probabilities of source locations from known impacted resources (backward tracking). This model was originally developed for use in oil spill tracking but can be similarly used to track other pollutants, such as fecal coliforms, as well.



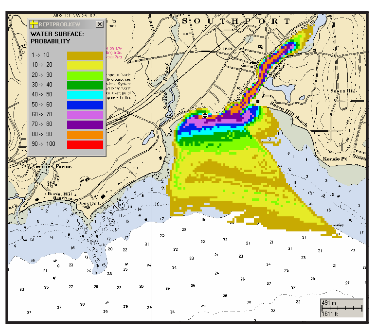
Forward mode particle transport model results showing transport probabilities for a source in Sasco Brook.



Forward mode particle transport model results showing transport probabilities for a source in Mill River.



Backward mode particle transport model results showing probabilities of the source locations that affect receptor location 1.



Backward mode particle transport model results showing probabilities of the source locations that affect receptor location 3.

Collectively, the integrated model systems identify the location and relative probability of sources that cause elevated FC concentrations over the shellfish beds in Southport Harbor.

SUMMARY

A field program and modeling study was conducted to assess likely sources of elevated fecal coliform levels at Southport Beach in Southport Harbor, Connecticut. The field program consisted of physical measurements (water level elevation and currents), bacterial measurements and dye studies.

The hydrodynamic model was successfully calibrated to the field data and showed the complex nature of the tidal flows in Southport Harbor, varying from primarily east-west flow in Long Island Sound south of the Harbor to primarily north-south flow in the Mill River to the north.

Particle based modeling was applied in both forward and backward modes. A series of likely source locations was run in forward mode and indicated plumes originating in Mill River were more likely to impact the Beach area than those from Sasco Brook. The backward mode results showed that the Mill River was the likely source based on six representative receptor sites located in the Beach area. Control of the Mill River sources is thus more likely to improve water quality at Southport Beach than control of Sasco Brook sources.

OTHER APPLICATIONS

Total Maximum Daily Load

Modeling results were used to support a bacteria Total Maximum Daily Load (TMDL) for Southport Harbor prepared by CTDEP in 2007.

Forecasting

The model system can be adapted to provide a forecasting capability for beach water quality via two approaches:

1. Use model in stochastic mode:

- Create a database of likely pollutant concentrations based on random sampling of historical environmental data forcing such as precipitation, winds, tides, temperatures, salinities, etc.
- Develop regression equations to determine the most important environmental factors governing water quality.
- Use regression equations and forecasted environmental factors to estimate future water quality.

2. Use model directly to forecast future water quality based on forecasted environmental factors.

Data requirements include specific pollutant source location information for use in models as well as high
resolution forecasted environmental variables provided by Integrated Offshore Observing Systems.

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